PROIOXIS

DESIGN & ENGINEERING



CAR DESIGN GOALS

To reach the maximum result possible we set a few goal for our self, which where:

- Speed - Make the car produce the fastest race time as possible
- Resistence - Avoid the breacking of the car during the race
- Innovation - Introduce as much innovation as possibol by still following the regulations and improving the car
- Consistent - Enhance the production quality to minimyze risk and pruduction waste

ALGORITHM

The **first step** in the manufacturing of our car was the **production of** what we call **"The Algorithm"**; the so called algorithm is an excel spread sheet in which are concentrated all the formulas to calculate every variable that can affect the car.
The Algorithm also contains the percentages of influence that a single variable applies, when modified, to the car itself.

APPLIED VARIABLES

[redacted]

CALCULATION METHOD

[redacted]

ANALYSED ELEMENTS

[redacted]

IMPACTS AND STUDY

For each variable, we took the basic formula and analyzed its influence, translating these considerations into design ideas. **For each formula, we highlighted the parameters we could modify**.
Each section explains the concepts we began development with, but to be sure, we still ran tests, which were also useful for algorithm validation. These tests will be explained later (page 11).

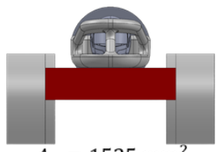
DRAG

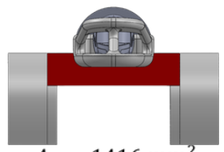
$$F_{Drag} = \frac{1}{2} \times \rho \times C_x \times A_{frontal} \times V^2$$

We can modify the force generated by drag to our **advantage by improving the Cx and the frontal area**.

FRONTAL AREA

To reduce drag, we **tested various types of packaging using CFD analysis**. The **goal was to minimize the frontal area** determined by the fixed elements (cylinder, halo, helmet, wheels, and virtual cargo). Obviously, the choice of the best value must be validated with CFD tests.





Frontal area calculation
Credits: ProioxisRT

Cx

The Cx depends on the quality of the car's geometry, it is necessary to **avoid** designs with **very acute angles between the surfaces**, avoiding **blocking the air** or **increasing fluid dynamic losses**, reducing the Magnus effect and Tyre wake effect as much as possible, and using aerodynamic profiles with a teardrop section (incidence angle and chamber = 0°).

WHEEL

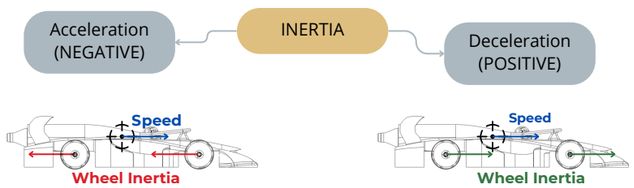
INERTIA

Wheel inertia formula
Credits: ProioxisRT

$$F_{Wheel\ Inertia} = \frac{\emptyset_{Wheel}}{2} \times (J_{Inertia} \times \varepsilon)$$

$$J_{Inertia} = m_{Wheel} \times R_{Average}^2$$

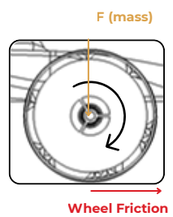
The **inertia of the wheels**, as shown by the energy analysis based on the algorithm, is **negative during acceleration** but **positive during deceleration**. This is because during acceleration the force is opposite to the motion, while during deceleration it is in agreement with the motion.



After these considerations, however, our task remains to decide the best value for performance by **changing the average radius** of the geometry **and the total mass** of the wheel.

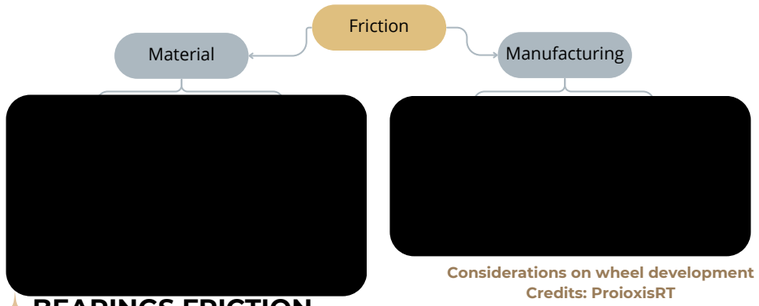


$$F_{Fri.\ wheels} = (m_{car} \times g) \times \mu$$



FRICTION

Rolling friction depends on the deformation, the wheel's surface, and its shape. Any imperfection cause micro-jumps that waste energy. Therefore, **when developing a wheel, the manufacturing method is as important as the chosen material**.

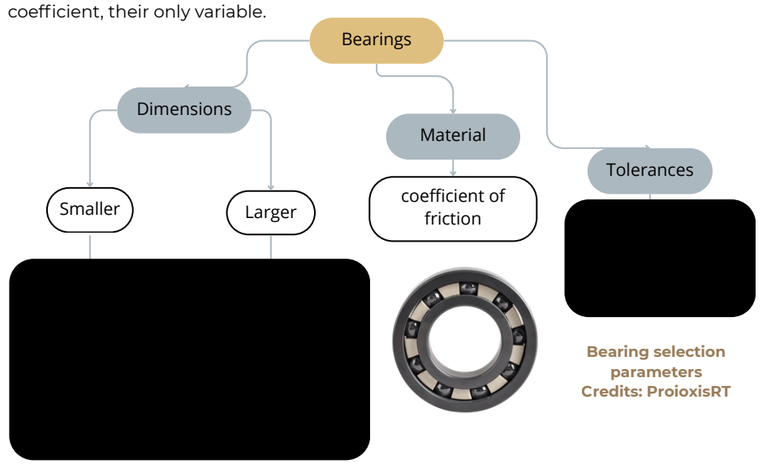


Considerations on wheel development
Credits: ProioxisRT

BEARINGS FRICTION

$$F_{Fri.\ bearings} = ((m_{car} - m_{wheels} \times g) \times \mu$$

Since **we can only purchase bearings**, not manufacture them, we've **chosen** the best ones **based on size and material**. These factors influence the friction coefficient, their only variable.

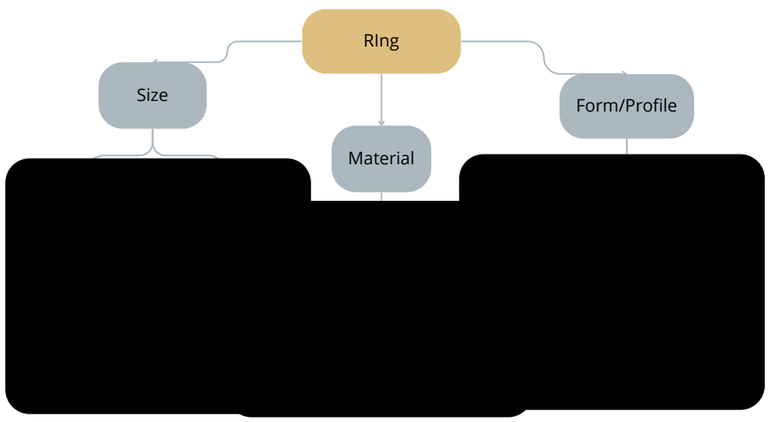


Bearing selection parameters
Credits: ProioxisRT

RINGS FRICTION

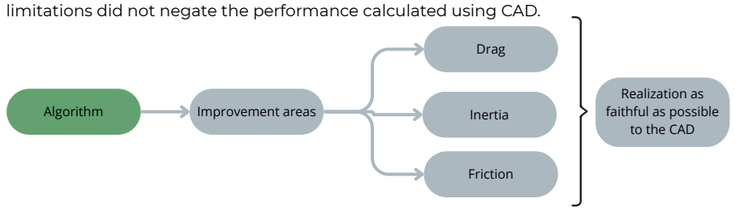
$$F_{Fri.\ rings} = F_{vertical} \times \mu$$

The choice of rings is based on the research for the best component by **evaluating size, material and profile**. To minimize friction, the selection focuses on technologies that offer an **ultra-smooth surface** and an **optimized profile**, preventing deformation and **ensuring perfect sliding**.

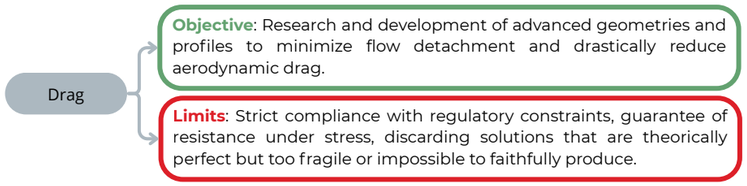


INITIAL PROCESS

Once the virtual cargo's positioning was defined, sensory analysis guided R&D to minimize drag, inertia, and friction. The algorithm, however, simulates an ideal world of non-deformable bodies and perfect geometries. In practice, pushing a theorical design to the extremes clashes with reality: a wheel with minimal inertia loses all its advantages if it flexes under stress, just as a perfect aerodynamic shape is useless if the manufacturing method cannot replicate it with absolute precision. R&D therefore also focused on workability, structural integrity, and assembly tolerances, ensuring that manufacturing limitations did not negate the performance calculated using CAD.



DRAG



VIRTUAL CARGO POSITION



FRONT PART

R&D was structured as a sequential process, **starting** with the **front end**. Since this is the area that first affects the flow of the entire car, **validating these geometries** was our **first goal**. **Developing** the **rear end on a temporary front end** would have **generated unnecessary CFD iterations and unreliable data**. Once we had achieved a nearly final geometry, we moved on to developing the subsequent components.

VERSION 1 OF WING

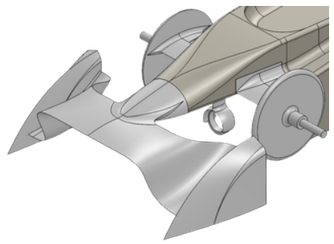
Version 1 was developed with the **primary goal of minimizing the frontal section**. By **aligning the flap with** the overall **profile of the car body**, we effectively reduced the exposed frontal area. However, **flow analysis highlighted a critical issue**: this geometry **compromised the aerodynamic coverage** effect **on the front wheel**, exposing it excessively and generating suboptimal turbulence downstream.



PROS:
Minimal frontal section.

First wing test
Credits: ProioxisRT

CONS:
Minimum wheel coverage.



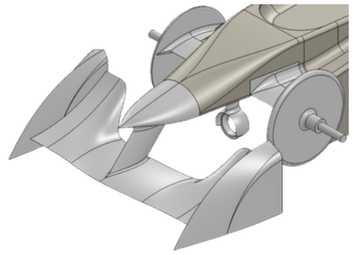
VERSION 2 OF WING

With Version 2, we aimed to **restore the aerodynamic efficiency** of the volumes permitted by the previous regulations, which allowed for **optimal flow deflection around the front wheel**. By modifying the inclination and integration of the flap with the endplate, we achieved a result almost identical to the solution no longer available, effectively circumventing the new dimensional constraints.



PROS:
Greater aerodynamic coverage.

CONS:
High impact on the underside of the wheel.



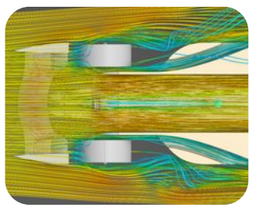
Second wing test
Credits: ProioxisRT

VERSION 3 OF WING



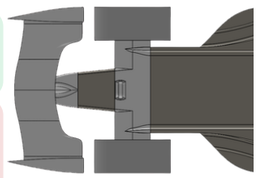
VERSION 1 OF THE FRONT UNDER BODY

The entrance to **the central channel was integrated with the front support**. The goal was to guide the flow in a more controlled and regular manner towards the external channel of the sidepods, anticipating the beginning of the channel itself and shaping the non-machinable end like a true aerodynamic flap. However, tests highlighted **two critical issues**: the solution drastically **limited the air flow to the external part** and created **problems with the flow returning inside the central channel**.



PROS:
It accompanies the wing flows inside the channel.

CONS:
It limits the air flow and causes problems in the duct flow.



First version of the underbody test
Credits: ProioxisRT

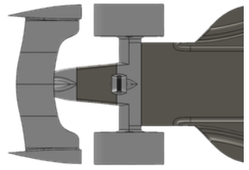
VERSION 2 OF THE FRONT UNDER BODY

In the optimized version, the **integration with the front support has been eliminated**, thus allowing the **entrance to the central channel** to be **moved back**. This modification has significantly **increased the flow capacity** directed towards the external channels of the sidepods. Furthermore, **the new geometry has resolved the harmful flow backflow into the central channel**, restoring a clean and smooth flow inside.



PROS:
Increased flow rate in the channel and resolution of flow backflow.

CONS:
It is not possible to convey the flows starting from the front axle.

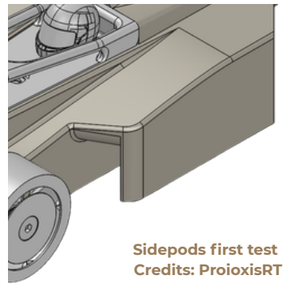


Second version of the underbody test
Credits: ProioxisRT

CENTRAL SECTION

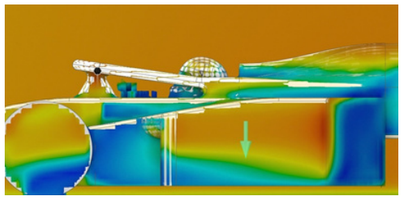
The purpose of the car's central section is to **shield and isolate the rear wheels from the harmful impact of airflow, both from the front and the outside**. At the same time, this area is designed to regulate the flow, channeling it cleanly and efficiently towards the rear.

VERSION 1 OF THE SIDEPODS

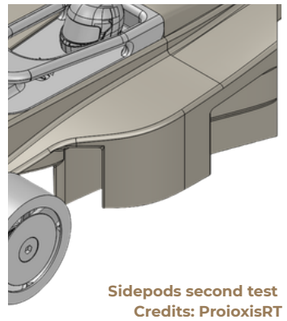


Sidepods first test
Credits: ProioxisRT

This first version aimed to provide optimal coverage of the rear wheels, minimizing airflow deviation. The focus was on simple, linear geometries to **better regulate the flow**, but this created **damaging pressure peaks** at the initial part of the belly.

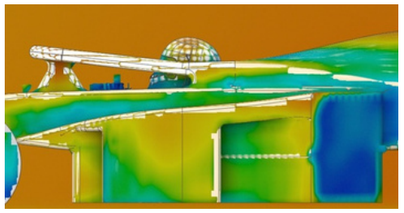


VERSION 2 OF THE SIDEPODS



Sidepods second test
Credits: ProioxisRT

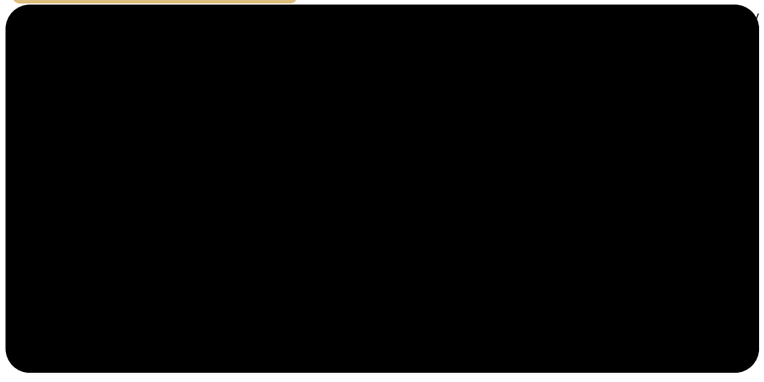
This second version aimed to solve the problems encountered in the previous one, **reducing the pressure peak at the beginning of the belly** and introducing a channel to divert the flow towards the outside, so as to better isolate the wheel from the return of lateral flows, however **the pressure peak was still too high.**



VERSION 3 OF THE SIDEPODS

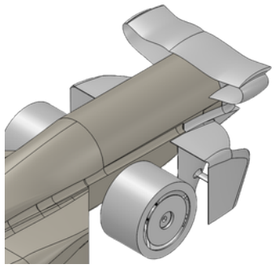


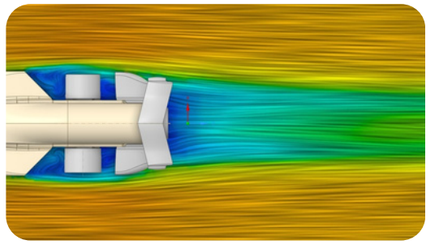
VERSION 4 OF THE SIDEPODS



REAR SECTION

The rear section of the car is designed to optimally direct airflow, minimizing wake turbulence. The **goal** is to **drastically reduce harmful vortices generated by air displacement**, thus improving overall aerodynamic efficiency.



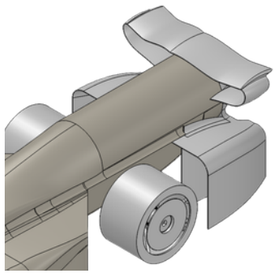


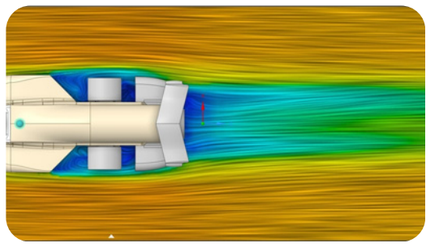
Rear section first test
Credits: ProioxisRT

This first version aimed to mitigate the low-pressure area in the wake of the rear wheels, directing the flows to restore a regular aerodynamic regime. The system's effectiveness, however, was limited by insufficiently sized profiles and shapes that did not align with the actual flow pattern.

PROS:
Optimal flow convergence to reduce harmful vortices.

CONS:
Limits efficiency against target due to insufficient profile size.





Rear section second test
Credits: ProioxisRT

The second version adjusted the geometry and dimensions of the appendages to maximize flow control. The aerodynamic benefits, however, were offset by an excessive increase in weight, which compromised the car's overall performance.

PROS:
Fixed issues encountered with the previous version, maximizing flow control.

CONS:
Excessive weight increase that nullifies the applied changes.

[redacted]

INERTIA

The study conducted on rotational inertia was crucial to maximizing the vehicle's acceleration and dynamic stability. Our R&D on the wheel assembly focused on two pillars: advanced manufacturing techniques and the use of low-specific-weight materials, rigorously selected to maintain the high stiffness necessary to prevent deformation. The goal is to empty the peripheral geometries to reduce the moment of inertia while still ensuring maximum reliability.

Inertia

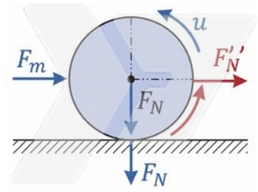
Objective: Research and development of optimised geometries to minimise the rotational inertia of unsprung masses (wheels), supported by a targeted selection of materials.

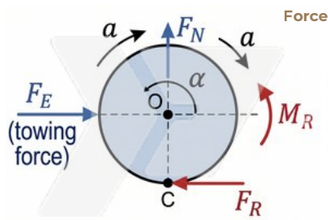
Limits: Compliance with regulatory constraints, guarantee of dimensional stability under stress and compliance with coupling tolerances and maintenance of an optimal surface finish.

WHEEL FRICTION AND GRIP

This point kinematically bends the physics of rolling friction and the **limit beyond which the body loses traction and begins to slip**, thus we were able to better understand the behavior of the wheel.

Contact at rest: The weight presses the wheel into the ground creating a symmetrical pressure area that can be calculated using Hertz's theory.





Force analisis credits:
AI

Rolling Friction: When the wheel rolls, the pressure zone moves forward by a distance u. This asymmetrical displacement generates the resisting force that opposes the motion.

Perfect rolling: the wheel turns without slipping only if the rolling friction coefficient is less than or equal to the grip of the ground (f rolling <= f sliding).

Worst condition

Skidding: Occurs if the driving force exceeds the limit of grip or if the ground suddenly becomes slippery.

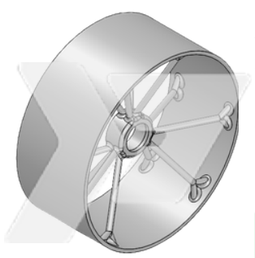
SOLUTIONS FOUND



The first concept (V1) was carved directly from the official polyurethane foam block, exploiting its extremely low density to eliminate inertia. Practical testing, however, highlighted critical issues: the material's marked surface roughness drastically increased rolling friction when in contact with the track, while its high deformability under load severely compromised the car's dynamic stability.

PROS:
Very low weight as they are obtained from the supplied polyurethane block.

CONS:
Limited performance due to high roughness and low load resistance.

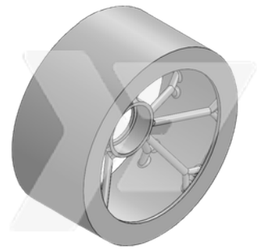


Wheels images
Credits: ProioxisRT

To overcome the limitations of the V1, the second iteration, 3D printed in PA12, incorporates a new double-triangle internal geometry. This design choice allowed us to optimize the distribution of stresses without having to thicken the profiles. This solution represents our best architecture, offering the perfect balance between reducing rotational inertia and the stiffness required on the track.

PROS:
Thanks to the internal structure and the new material, resistance has been significantly improved.

CONS:
Lack of the necessary border for Pirelli stickers.



Wheel image
Credits: ProioxisRT

The final version (V-Race) optimizes the V2 with two changes. First, prolonged testing at very high RPMs highlighted premature wear of the micro-bearings. The adoption of a larger diameter resolved the performance decline, ensuring reliability without penalizing inertia. Second, in preparation for the National Championships, the perimeter band for the mandatory Pirelli sticker was integrated, absorbing the regulatory constraint without compromising overall efficiency.

PROS:
After testing at high RPM we changed the bearings to overcome the wear problem, and we also added the shoulder for the Pirelli sticker.

FRICTION

Tribological studies and mechanical friction optimization focused on advanced material selection. The R&D objective was to identify the best engineering compromise to minimize the sliding and rolling friction coefficients, drastically reducing energy dissipation based on the specific dynamics of our vehicle.

Friction

Objective: Research into materials and processes aimed at reducing rolling and sliding friction, optimizing overall mechanical smoothness.

Limits: Compliance with regulatory constraints, guarantee of dimensional stability under stress and maintenance of sustainable costs.

RINGS

The guide design focused on drastically reducing sliding friction when in contact with the nylon line. To minimize dissipation, we selected the best option on the market, adopting

[redacted]

Technical Parameter	Steel
Line Pressure	> 150%
Surface Roughness [Ra]	~ 0.20 / 0.30
Hardness [HV]	~ 1.5 – 2.5
Density (g/cm^3)	~ 7.80
Coefficient of Friction (COF)	~ 0.35 - 0.45

[redacted]

BEARINGS

The selection of the ideal bearing was guided by a rigorous performance target: to simultaneously minimize the moment of inertia and the coefficient of friction, while ensuring consistent performance even under prolonged stress and extreme rotation speeds.



The starting bearing, due to its excessive diameter, had a negative impact on mass and inertia. The choice of conventional materials—plastic raceways and glass balls—further limited performance.

Mass : 0.226 g **External diameter** : 10 mm

[redacted]

CAD CRITERIA

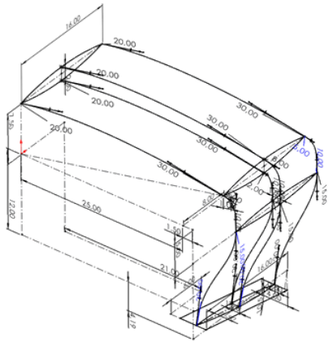
We chose to use SolidWorks for the 3D modeling of our prototype, as it met the following requirements:

- Improved assembly file management with advanced coupling. Once a project becomes full of versions, it allows you to manage them without using too much processing power.
- Both designers had excellent prior knowledge of the program and were granted a free license through the school.
- Availability of complex functions that allowed us to create the shapes we wanted
- Ability to perform FEM simulations always using a SolidWorks application, simplifying and speeding up design changes.

FUNCTION UTILIZED

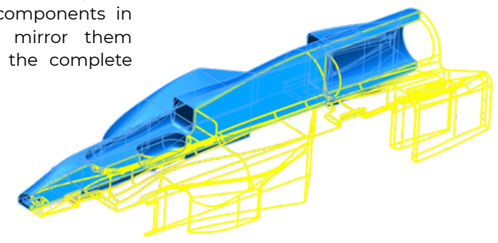
3D SKETCHES

To avoid line alignment errors and potential program crashes due to changes that would create impossible measurements for some lines, for example, we opted for the rear wing to draw the entire component with a 3D sketch, inserting into it all the sketches and guidelines needed to shape it with a loft later.



MIRROR

To avoid asymmetry errors in future modifications, we decided to draw only half of all our components in CAD, then mirror them and create the complete piece.

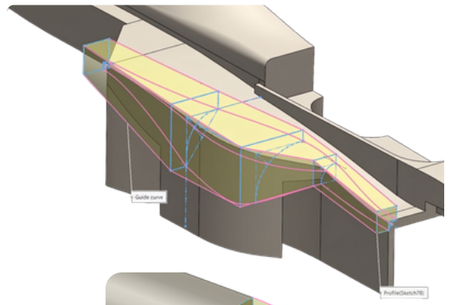




Utilized functions
Credits: ProioxisRT

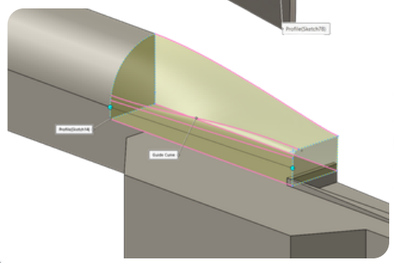
CUT IN LOFT

Loft cutting is a useful feature when the length to be joined is a broken line, and using variable fillets would make the join look uneven. However, using loft cutting, by sketching along the length and drawing guidelines, certainly yields a better result.



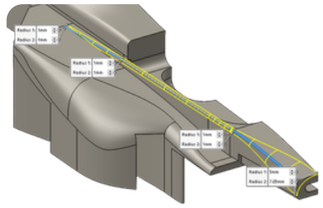
LOFT

We used loft to avoid multiple cuts after an extrusion to result in complex, variable-profile geometry along multiple sketches.



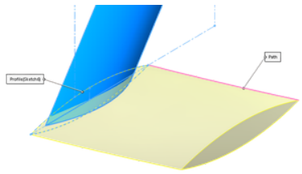
FITTINGS VARIABLE

To help us blend sharp surfaces as smoothly as possible, as they often have variable thicknesses, we opted for variable radius blends. This feature allows for various blend settings along the length to be blended, also simplifying the modification (avoiding the need for multiple blends in series).



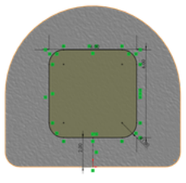
SWEEP

Unlike lofts, we used sweeps to create airfoils or other constant-section component parts. By drawing the basic sketch on a plane and the guideline that determines the sweep path in 3D, we created a beautiful, uniform surface, without having to use multiple extrusions with subsequent fillets.

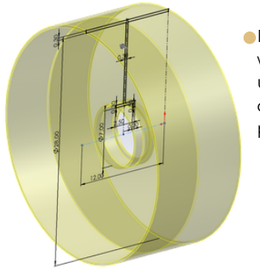


3D PARAMETER

The initial **parametric approach**, aimed at automating aerodynamic optimization, **required excessive setup times**. Furthermore, due to an initially crude mesh, entrusting the design selection to the software generated inconsistent and unreliable results. We therefore **abandoned parameters in favor of "clean" CAD modeling**, thus **eliminating the risk of errors and reference loss during manual iterations** (as shown in the figure).



- Sketches always constrained to the CAD origin (not to other surfaces/features).



- Functions with well-defined unique sketches on a dedicated plane

Examples of CAD methods used in sketches/functions
Credits: ProioxisRT

ZEBRA-CHECK OF THE CAR

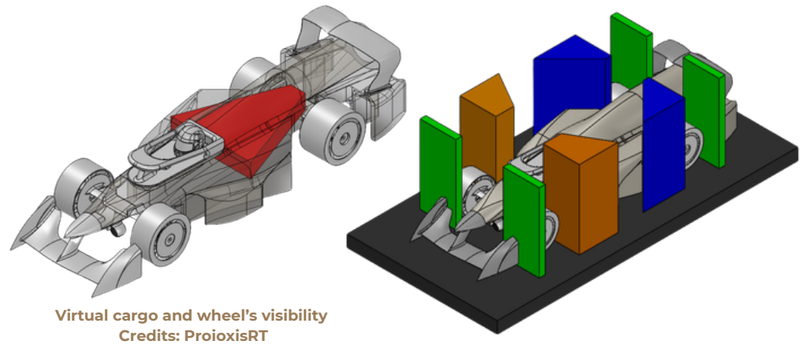
To **avoid exporting corrupt CAD files or files with transparent surfaces that would later create problems in CFD (mesh) and in the hypothetical production of the various parts**, we used the SolidWorks function (Zebra strips) to visually inspect all the machine's surfaces. The **goal is to find lines that converge at a point on a flat surface, curvatures in surfaces that should be flat**, and much more. This allows us not only to **prevent** certain **problems** but also to best realize our ideas for the machine.



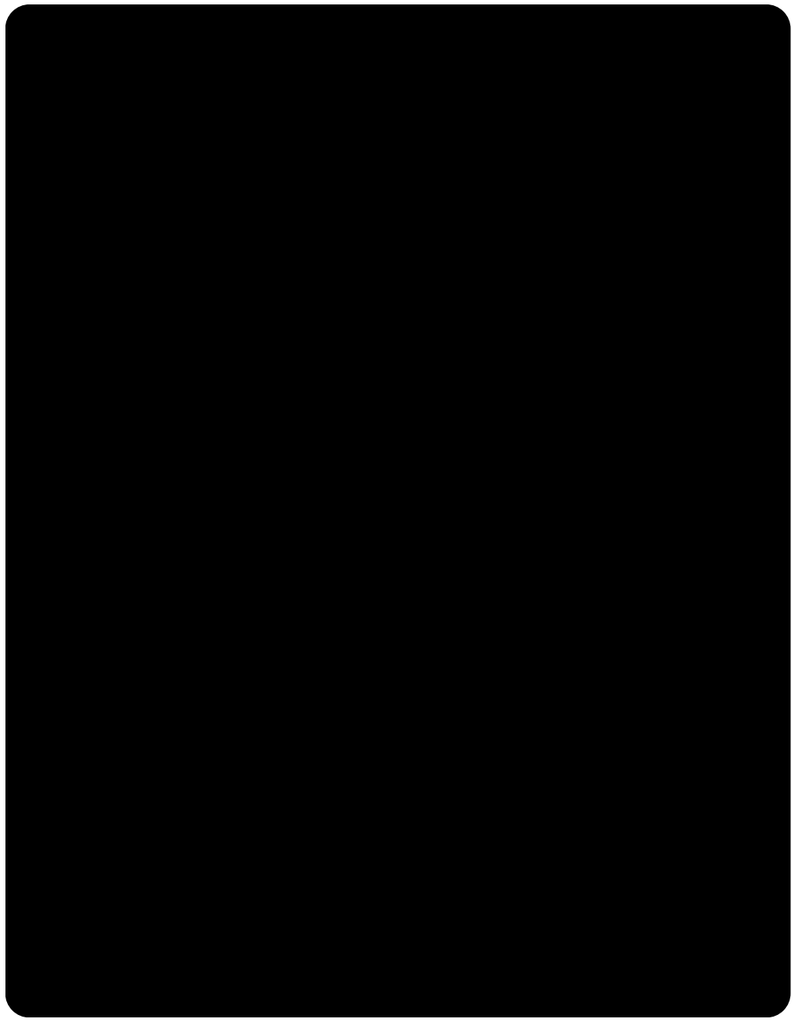
Analisi Zebra strips
Credits: ProioxisRT

CHECKING RULES

To avoid wasting time rechecking technical regulations after each change, **we created virtual volumes (cargo, wheel visibility limits and F1 model block) with exact imposed measurements**. Building this volumes olso helped us ensure that the car was compliant with the regulations to avoid further probles.



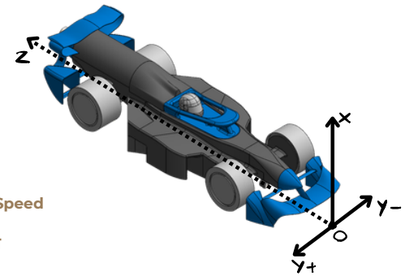
Virtual cargo and wheel's visibility
Credits: ProioxisRT



MULTI-COMPONENT MODELLING

Direct assembly modeling ensures alignment and seamless change management thanks to parametric associativity between parts. This approach allows for real-time design refinement, ensuring seamless geometric integration between each component.

AXLE X,Y,Z



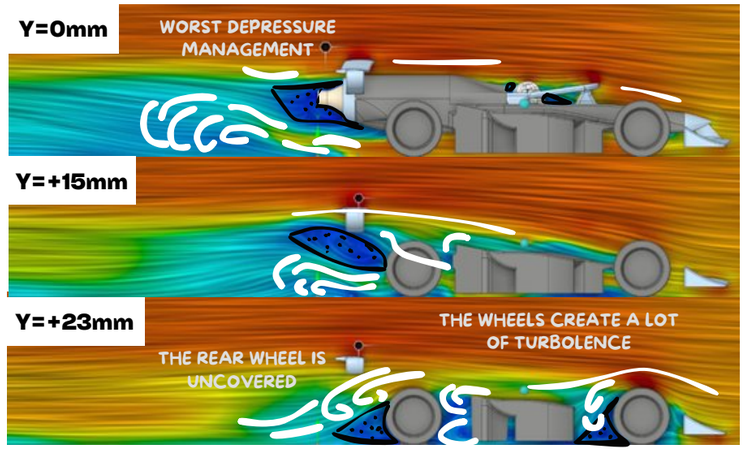
Position of the car and Speed Criteria
Credits: ProioxisRT

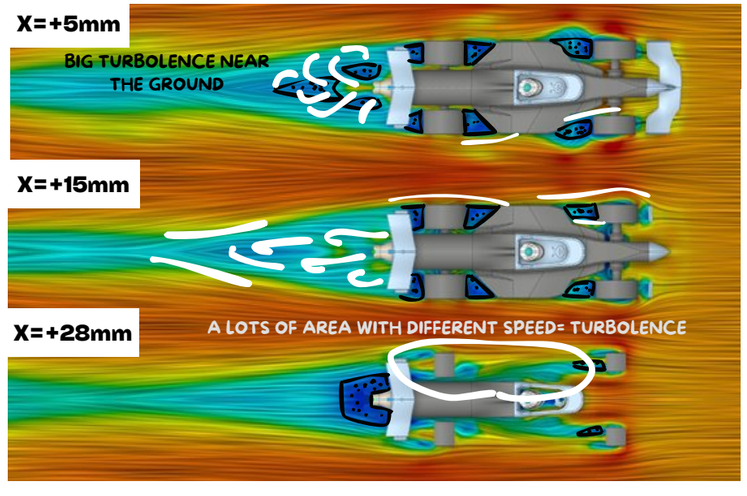
FIRST SIMULATION

PR-05C

This is the car we used for mesh development, our 2026 qualifying car. It has obvious problems, mainly related to the hollow wheels supplied by Stem Racing, as well as the enormous vacuum behind the car. Furthermore, the flows are not linear.

- **Worst management of depression behind the machine** — General Geometry Problem
- **Wheels, especially the rear ones, which create a lot of turbulence and which are not covered by the air** — Wheel Geometry problem
- **Areas with very different speeds very close to each other, a symptom of turbulence** — Sidepods Geometry Problem





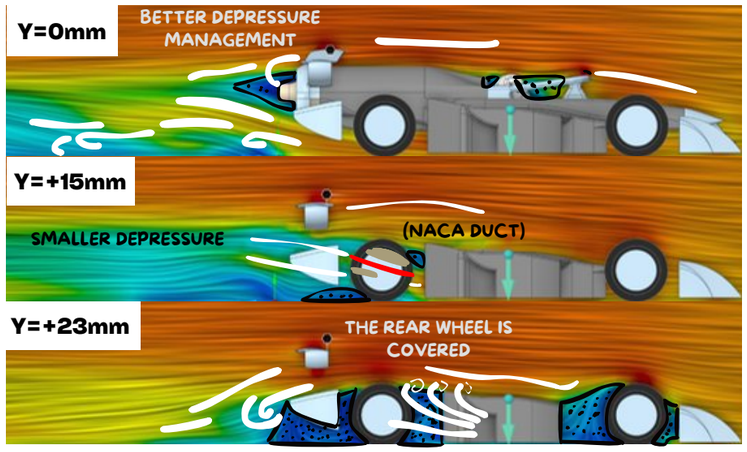
PRECISION OF THE SIMULATION

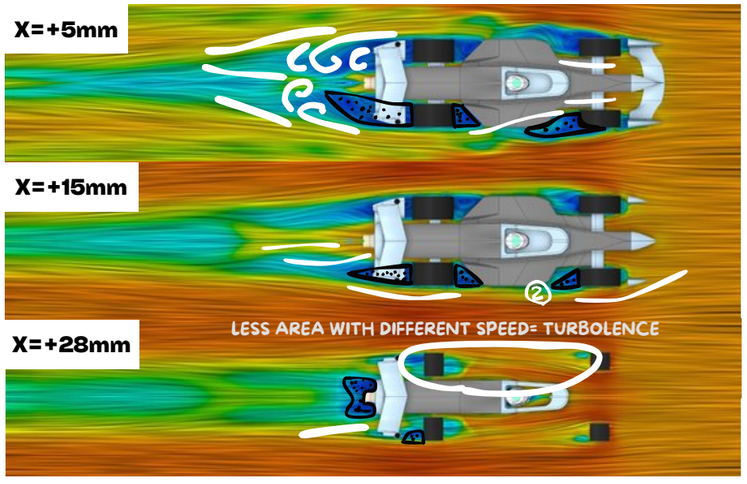
Value (Algoritmo) Cd [/]	Value (Simulation) Cd [/]	ERROR [%]
0,897	0,905	+0,89 % (<5%)

PRO5D

This prototype is the first development path we chose, which was to develop the existing project. The first thing we did was revise the front wing, so that the sidepods would work much better, and also redesign the wheels to eliminate the problem of the previous cavity.

- **Lower depression behind the car, improvement over the PR05C** — General Geometry Update
- **Improved wheel handling, although still having high overall drag (+ NACA DUCT)** — Wheel Geometry Update
- **Areas with very different speeds between them very close together reduced** — Sidepods Geometry Update



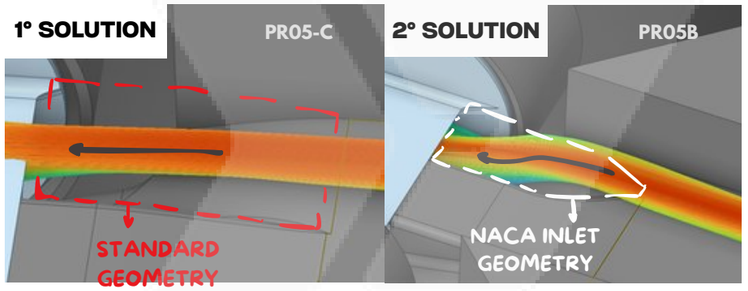


PRECISION OF THE SIMULATION

Value (Algoritmo) Cd [/]	Value (Simulation) Cd [/]	ERROR [%]
0,714	0,721	+0,98 % (<5%)

NACA DUCT

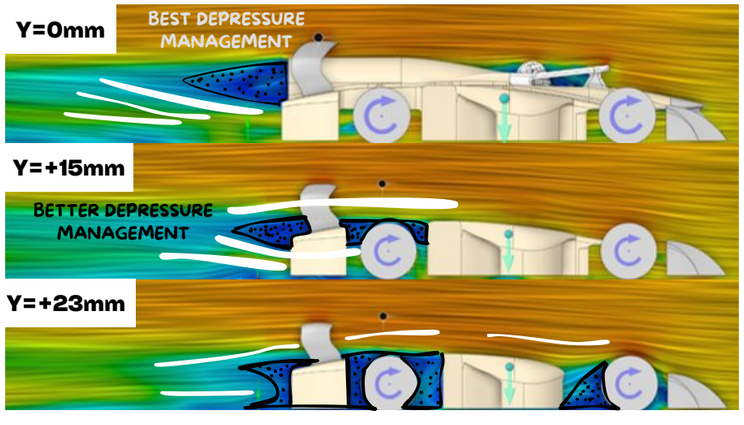
The implementation of NACA geometry (PRO5B) dramatically reduces aerodynamic drag compared to the standard design (PRO5-C). Simulations confirm that this profile channels fluid toward the rear axle more efficiently, keeping it close to the surfaces. This limits flow detachment, significantly reducing both turbulence and the area of depression in the vehicle's wake.



Naca inlet development
Credits: ProioxisRT

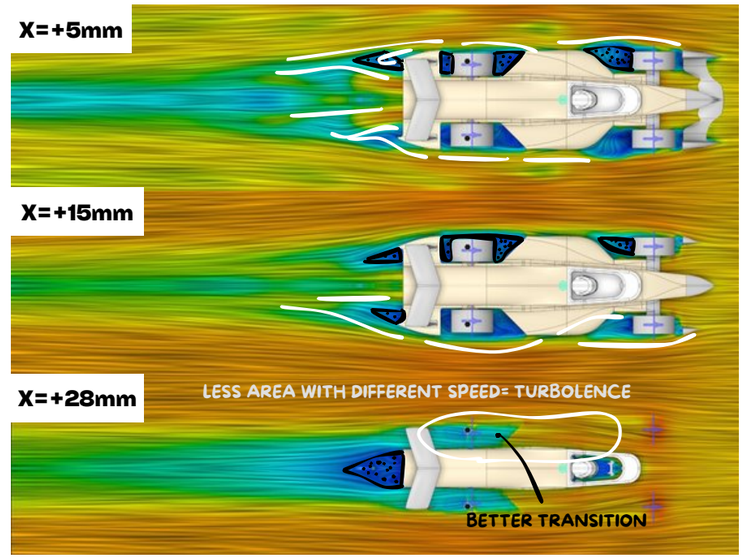
PRO6

[redacted]



PRECISION OF THE SIMULATION

[redacted]



[redacted]

VERIFY THE GOAL

[redacted]

PROGRAM USED

To perform the FEM tests we used SOLIDWORKS

MESH PARAMETERS

The first thing we did was define the **mesh parameters**:

- Body sizing - 1.6 mm
- Face sizing - 0.7 mm

Face sizing is applied to the surface on which the force acts.
After defining these parameters, we performed **FEM tests**. Some tests were **performed to verify that our car could pass the physical tests required during scrutineering** at the National Championships, while other tests were conducted internally within the team to analyze structural issues found on some components and evaluate the strength of the new design.

WHEELS

The wheel test involves attaching a **100 g mass** to three equally spaced hooks to keep the wheel evenly balanced.

[redacted]

Looking at the stress scale we notice that in the simulation performed **the wheel resists the test** because we know that PA12 resists up to approximately 40 MPa.

	σu	STRESS MAX
WHEEL	40 Mpa	13,69 MPa

HALO

The test performed on the halo consists of **applying a 2 kg mass** against it to verify that, **during** the various **competition throws**, **the halo does not break upon impact with the wire at the end of the track.**

[redacted]

From the test results we note that the halo is also **suitable** for the test that will be carried out.

	σu	STRESS MAX
HALO	40 MPa	2,137 MPa

TETHER LINE GUIDES

The final test to verify the scruteenering results is the one on the hooks through which the track wire passes.
This test involves **applying 200 g directly to the hook**.

[redacted]

FRONT

The FEM test on the nose is one of those we wanted to perform to verify a critical component of our car.

The first thing to do was **redefine the mesh parameters**:

- Body dimensions - 1.2 mm

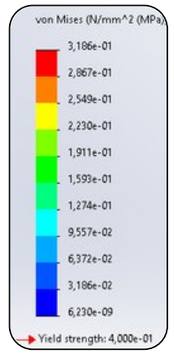
We then moved on to the actual test, **applying a force of 1.5 N inside the front wing attachment to verify** that the wing would not break **in the event of sudden braking that would cause the front wing to impact the ground**.

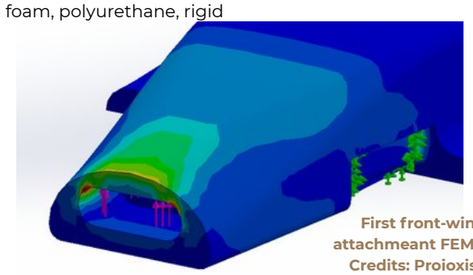
[redacted]

Image of applied force
Credits: ProioxisRT

Material:

- attachment front wing - foam, polyurethane, rigid





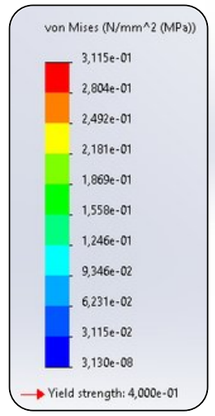
First front-wing attachmeant FEM test
Credits: ProioxisRT

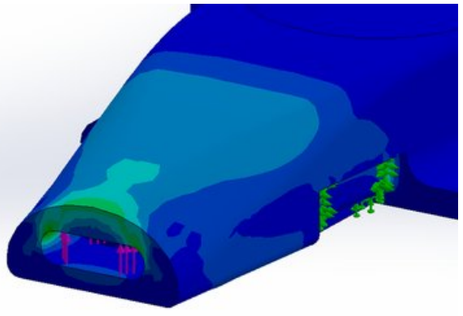
	σu	STRESS MAX
PUNTA	1,1 Mpa	0,319 MPa

Since the **maximum stress was close to breaking the material**, we decided to **increase the thickness of the attachment** in the car body, making better use of the space at our disposal.

[redacted]

Keeping the same material and the same applied forces we therefore went to perform a new test.





Second front-wing attachmeant FEM test
Credits: ProioxisRT

	σu	STRESS MAX
JOINT	1,1 Mpa	0,312 MPa

CONCLUSIONS

By reducing the cross-section of the front wing seat, we note that:

- the first model resisted a force of 1.5 N, which, however, was close to breaking the joint.
- the second model completely resisted the 1.5 N force applied inside the seat.

OBJECTIVE

- Rapid production
- Minimal waste of material
- Perfect surface
- Complies with the regulation

[redacted]

CAM

[redacted]

CAR BODY PROCESS

TOOLS

Used machine: Mazak CV5-500 (5 axes) Tools details Credits: ProjexisPT

[redacted]

3D PRINTING

Evaluation of three plastic materials:

MATERIALS	DENSITA' [g/cm^3]	DETAILS	FINISH
PA6	1,114	RIGID	RUVIDA
PA12	1,01	ELASTIC	LISCIA
RESINA	1,15-1,25	ELASTIC	LISCIA

Total mass of components:



The components for our machine were **supplied by**



HP Multijet Fusion printers for perfect surface finishes on the **PA12** components, and **Formlabs for** the **resin components**.

PA12 BENEFITS:
- Lower weight
- Paintable
- More flexible

RESIN BENEFITS:
- Low tolerances +- 0.1 mm
- Maintains geometric tolera nces better

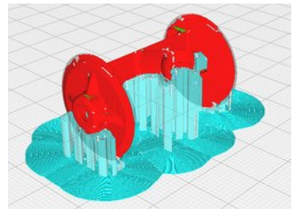


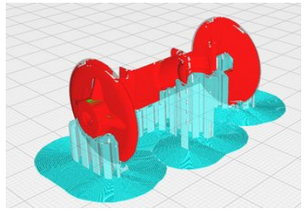
Some **components** are **printed in resin due to the tolerances that can be achieved with this type of printing**. This **process** was **applied only to the front and rear support** to ensure better coupling with other components.
The **achievable tolerances are +/- 0.1 mm for resin printing**, while for **PA12 printing**, tolerances of **+/- 0.2 mm** can be achieved.

PRINTING ORENTATIONAL OPTIMISATION

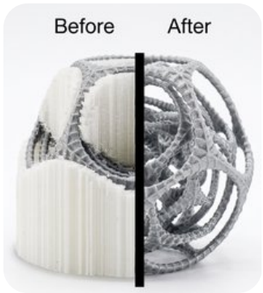
The **minimum thickness of a part needed to complete the 3D production is 0.75mm** to produce a strong enoughth part.
The **contours were printed with 75% powde**r whereas the **fill was printed with 100% powder**.
Parts that are **only produced of 75% powder are weaker than the ones presenting some type of fill**, that's why all **parts where orienteted to ensure all of our production contained some fill**.

SLICING





POST PROCESSING



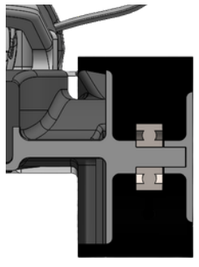
After molding the components, the supports must be removed. To do this, our sponsor creates the **supports from a different material**: ABS-like for the axles and PA12 for the rest of the components.
The **support material has the property of dissolving when water is poured on it**; this **solves the problem of the surface finish** of the components after removing the supports.

[redacted]

VEHICLE ASSEMBLY

Car assembly is a crucial step in maximizing the performance of the entire project, ensuring maximum fidelity to the 3D CAD model. For this reason, the **process** is **carried out with meticulous attention to mechanical fit tolerances and through rigorous preliminary selection of the best components**.

WHEEL GROUP ASSEMBLY



Before:

The **previous assembly system was unreliable**: the pin co-printed in 3D with the support had **serious geometric tolerance defects** (circularity and straightness), which **caused interference during assembly and extreme uncertainty of the entire system**.

CAD VERIFICATION PROCESS

Thanks to our partners and the previous versions of the various components produced, we are confident that the components manufactured conform to the measurements in the drawings.
The drawings were produced following the tolerances imposed on us by the regulations and our partners.